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Internet Use and Sleep Health among Empty-Nest Older Adults: A Longitudinal Study Based on the China Longitudinal Aging Social Survey

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Research Article

Keywords: Internet Use, Sleep Health, China, Older Adult, Empty Nesters

Posted Date: March 11th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8709331/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

With the rapid growth of the empty-nest older adults in China, increasing attention has been paid to their health status, particularly sleep health as an important component of overall well-being. Alongside ongoing digitalisation, Internet use among older adults has become increasingly widespread. However, empirical evidence on the association between Internet use and sleep health among empty-nest older adults remains limited. This study aims to examine the association between Internet use and sleep health in this population.

Methods

Data were drawn from the 2020 and 2023 waves of the China Longitudinal Aging Social Survey (CLASS), including 6,894 empty-nest older adults. Two-way fixed-effects regression models were used to estimate the association between Internet use and sleep health while controlling for unobserved time-invariant individual characteristics and common period effects. Further analyses explored heterogeneity by age group and residential setting and distinguished between different functional types of Internet use to examine their differential associations with sleep health.

Results

Internet use was significantly and positively associated with better sleep health among empty-nest older adults. Compared with non-users, those who used the Internet reported higher levels of sleep health. Notable age-related heterogeneity was observed. Among younger and middle-aged empty-nest older adults, daily Internet use showed a stronger positive association with sleep health, whereas among the oldest-old, frequent but non-daily use was more strongly associated with improved sleep health. The positive association between Internet use and sleep health was broadly consistent across residential contexts. When disaggregated by functional type, only information entertainment type was significantly associated with better sleep health, whereas social interaction and tool founction types showed no significant associations.

Conclusions

Internet use is positively associated with sleep health among empty-nest older adults in China, although this association varies by age and by the type of online activity. These findings suggest that the health implications of digital engagement in later life depend not only on access and frequency but also on usage patterns and living arrangements. Promoting age-appropriate and purposeful internet use may

represent a feasible strategy for improving sleep health and overall well-being among empty-nest older adults in rapidly ageing societies.

1 Introduction

Population ageing, declining fertility, and increasing geographic mobility have substantially reshaped family structures in China, leading to a rapid growth in the number of empty-nest older adults. According to statistics from the Ministry of Civil Affairs of the People's Republic of China, by 2022, the proportion of empty-nest older adults had exceeded half, reaching over 70% in some major cities and rural areas[1]. Empty-nest older adults are commonly defined as individuals aged 60 years and above who live without adult children, either alone or only with an older spouse[2]. This living arrangement has become an important household pattern in later life and is often associated with reduced daily family support and increased risks of social isolation and psychological vulnerability. Compared with older adults who co-reside with family members, empty-nest older adults are more likely to experience emotional distress, unmet care needs, and adverse health outcomes, making them a particularly vulnerable subgroup in the ageing population.

Sleep health is a core component of healthy ageing and plays a critical role in maintaining physical, cognitive, and emotional functioning in later life[3–5]. Accumulating evidence indicates that poor sleep quality and sleep-related problems among older adults are associated with a wide range of adverse outcomes, including cardiovascular disease, cognitive decline, depression, and increased mortality risk[6–9]. Sleep health encompasses not only sleep duration but also subjective sleep quality and sleep-related symptoms, highlighting its multidimensional nature. Given the high prevalence of sleep problems in older populations, identifying modifiable behavioral and social determinants of sleep health has become an important public health priority.

In parallel with demographic ageing, rapid digitalization has substantially reshaped the daily lives of older adults in China. Internet use among individuals aged 60 years and above has increased markedly in recent years, enabling access to information, communication, and various online services. As of June 2024, the number of internet users aged 60 and above in China reached 157 million, accounting for 52.95% of older adults aged 60 and above[10]. For many older adults, especially those with limited mobility or restricted social networks, the Internet has become an important channel for maintaining social connections, obtaining health-related information, and engaging in leisure activities. Consequently, Internet use has been increasingly recognized as a potential determinant of older adults' health and well-being[11].

Against this backdrop, the association between Internet use and sleep health among older adults has emerged as an important topic at the intersection of geriatric health and digital sociology. Despite extensive academic research, no consensus has yet been reached on whether Internet use functions as a "health promoter" or a "sleep disruptor". Some studies suggest that Internet use may promote better sleep health by enhancing social participation, reducing loneliness, and improving health literacy[12, 13].

Improved access to health information and emotional support through online communication may indirectly contribute to more regular daily routines and healthier lifestyles, which are beneficial for sleep[14]. Recent longitudinal research has further indicated that moderate Internet use may be associated with better sleep quality and longer sleep duration among middle-aged and older adults[15]. Conversely, other studies have raised concerns that excessive or poorly timed Internet use may disrupt sleep through delayed bedtime, increased cognitive arousal, exposure to bright screens at night, and the development of problematic or addictive use behaviors[16, 17]. Nighttime engagement with social media, videos, or online content may interfere with circadian rhythms and increase the risk of insomnia symptoms and shortened sleep duration[18, 19]. Furthermore, overreliance on online interactions may crowd out offline social activities, narrowing older adults' real-world social networks and exacerbating social isolation, which is itself detrimental to mental health and sleep stability[20]. Several studies have also reported weak or non-significant associations between Internet use and sleep outcomes, suggesting that this relationship may depend on contextual and individual factors[21].

Despite growing scholarly attention, important gaps remain in the literature. First, most existing studies focus on the general older population and rarely consider the specific living arrangement of empty-nest older adults, whose health experiences may differ substantially due to reduced family support and distinct social environments. Family structure has been shown to play a crucial role in shaping both Internet use patterns and health behaviors, yet few studies explicitly examine how Internet use relates to sleep health within the context of empty-nest households. Second, much of the current evidence is based on cross-sectional data, which limits the ability to account for unobserved individual heterogeneity and to capture within-person changes over time. Longitudinal evidence remain scarce, particularly in low- and middle-income settings such as China, where both population ageing and digital transformation are occurring rapidly. Third, Internet use is often treated as a homogeneous behavior, with limited differentiation by functional types of use. Distinguishing between social interaction, information and entertainment, and tool function may provide a more nuanced understanding of how different online behaviors relate to sleep health.

Compared with non-empty-nest older adults, Internet use among empty-nest older adults may play a more complex and consequential role. On the one hand, Internet use can compensate for reduced face-to-face contact with adult children by facilitating communication and expanding social networks, thereby alleviating loneliness and psychological distress[22, 23], which are closely linked to sleep quality[24]. On the other hand, the absence of co-residing family members may reduce external regulation of daily routines and technology use, potentially increasing the risk of excessive or poorly timed Internet engagement[25]. These opposing mechanisms suggest that the association between Internet use and sleep health among empty-nest older adults may differ from that observed in the broader older population and warrants focused investigation.

Against this background, this study aims to examine the association between Internet use and sleep health among empty-nest older adults in China using nationally representative longitudinal data from the China Longitudinal Aging Social Survey (CLASS) collected in 2020 and 2023. By applying two-way fixed

effects regression models, this study accounts for unobserved individual-level time-invariant characteristics and period-specific effects, thereby providing more robust evidence on within-person associations between changes in Internet use and sleep health. In addition, we conduct extended analyses to explore whether the association varies by functional types of Internet use, including social interaction, information and entertainment, and tool function. This study seeks to improve understanding of the role of digital engagement in shaping sleep health among a rapidly growing and vulnerable segment of the older population and to inform targeted digital health and ageing policies in China and other ageing societies undergoing rapid digital transformation.

2 Methods

2.1 Data and study sample

Data for this study were drawn from the China Longitudinal Aging Social Survey (CLASS), jointly conducted by the Population and Development Research Center and the Institute of Gerontology at Renmin University of China. CLASS is a large-scale, nationally representative social survey of the older population in China. Since its inception in 2014, the survey has been carried out at intervals of approximately 2 – 3 years using a stratified, multistage probability sampling design. It covers 30 provinces across mainland China, includes more than 400 village- or community-level sampling units, and surveys over 10,000 adults aged 60 years and above in each wave. CLASS collects comprehensive information on respondents' socio-demographic characteristics, health status, living arrangements, social participation, and digital technology use, thereby providing rich measures of Internet use and self-reported sleep health among older adults. The present study utilized data from the 2020 and 2023 waves to construct the analytical sample.

The study sample was restricted to empty-nest older adults, defined as individuals aged 60 years and above who were living only with an older spouse at the time of the survey. Respondents living with adult children or other family members were excluded from the analysis. The combined 2020 and 2023 CLASS survey waves initially yielded 23,068 observations. A series of exclusion criteria were then applied. First, observations with coding errors or inconsistent identification information were removed. Second, to enable individual-level longitudinal analyses using fixed-effects models, respondents who did not appear in both survey waves were excluded. Third, observations with missing values in key variables, including Internet use and sleep health, were dropped. After these exclusions, the final analytical sample consisted of 6,894 observations. The detailed sample selection process is illustrated in Figure 1.

2.2 Measures

2.2.1 Frequency of Internet use

Frequency of Internet use was measured using respondents' self-reported answers to the question: "Do you use the Internet (including accessing the Internet via mobile phones or other electronic devices)?" Response options included never, several times a year, at least once a month, at least once a week, and every day. For analytical purposes, frequency of Internet use was recoded into a three-category ordinal variable. Respondents who reported never using the Internet were coded as 1. Those who reported using the Internet several times a year, at least once a month, or at least once a week were grouped and coded as 2, reflecting non-daily but regular Internet use. Respondents who reported using the Internet every day were coded as 3, indicating habitual Internet engagement. Higher values reflect greater frequency of Internet use.

2.2.2 Sleep health

Sleep health was measured using a single-item question adapted from the Center for Epidemiological Studies Depression Scale (CES-D)[26]: How often do you feel that your sleep was restless last week? Response options included never, sometimes, often, and unable to answer. Observations with responses of unable to answer were excluded from the analysis. Respondents who reported often experiencing poor sleep were coded as 1; those who reported sometimes were coded as 2; and those who reported never were coded as 3. Higher values indicate better sleep health.

2.2.3 Covariates

Based on prior empirical studies[15,27,28], a comprehensive set of covariates was included to adjust for potential confounding factors in the association between Internet use and sleep health. These covariates encompassed socio-demographic characteristics, family structure, lifestyle behaviors, and health status.

Age was categorized into three groups: 60 – 69 years (coded as 1), 70 – 79 years (coded as 2), and 80 years and above (coded as 3). Place of residence was classified as urban (1) or rural (0). Educational attainment was measured as years of formal schooling completed and treated as a continuous variable. Current work status was assessed using the question: "Are you currently engaged in paid work or income-generating activities?" Respondents were coded as 1 if they reported being currently at work and 0 otherwise. Family structure was captured using two binary indicators reflecting whether the respondent had at least one son (1 = yes) and at least one daughter (1 = yes). Life satisfaction was measured by the question: "Overall, how satisfied are you with your current life?" Responses of very dissatisfied and rather dissatisfied were combined and coded as 1, neither satisfied nor dissatisfied was coded as 2, and rather satisfied and very satisfied were combined and coded as 3. Exercise duration was assessed based on respondents' self-reported average time spent on physical exercise per session. Responses were categorized into four levels: less than 30 minutes (coded as 1), 30 – 59 minutes (coded as 2), 60 – 120 minutes (coded as 3), and more than 120 minutes (coded as 4). Health status variables included self-rated health, chronic disease status, and functional limitations. Self-rated health was

measured using the question: “How would you rate your current health status?” Responses of very unhealthy and rather unhealthy were combined and coded as 1; average was coded as 2; and rather healthy and very healthy were combined and coded as 3. Chronic disease status was defined as a binary variable, with respondents reporting at least one physician-diagnosed chronic condition coded as 1 and those reporting none coded as 0. Functional status was assessed using activities of daily living (ADL). CLASS includes six items: eating, dressing, toileting, bathing, transferring, and indoor mobility. For each item, respondents who reported not needing assistance were considered functionally independent, whereas those requiring any assistance were considered impaired. The total number of impaired ADL items was summed to generate a continuous measure of ADL limitations, with higher values indicating greater functional impairment.

2.3 Statistical analysis

Data were analyzed using Stata software version 18.0. Descriptive statistics were first calculated to summarize the characteristics of the study sample. Categorical variables were reported as numbers and percentages, while continuous variables were presented as means and standard deviations. To examine the association between Internet use and sleep health among empty-nest older adults, two-way fixed effects regression models were estimated using panel data from the 2020 and 2023 waves of CLASS. Specifically, individual fixed effects were included to control for all time-invariant characteristics at the respondent level, such as stable sociodemographic traits and unobserved individual heterogeneity. In addition, survey wave fixed effects were incorporated to account for common time trends and period-specific shocks across the 2020 and 2023 survey waves. All models adjusted for a set of covariates, including age, residence, work status, exercise duration, life satisfaction, self-rated health, chronic disease, and so on. Standard errors were clustered at the individual level to account for within-person correlation across survey waves. All statistical tests were two-sided, and a *p*-value of less than 0.05 was considered statistically significant. Regression coefficients and their corresponding 95% confidence intervals (CIs) are reported.

2.4 Ethics approval and consent to participate

This study used secondary data from the China Longitudinal Aging Social Survey (CLASS). All procedures involving human participants were conducted in accordance with the Declaration of Helsinki and its later amendments. The survey protocol was approved by the Academic Committee of School of Population and Health, Renmin University of China. Verbal informed consent was obtained from all participants prior to the interviews. Information on the consent process, including agreement to participate and reasons for refusal, was documented and archived by the Institute of Gerontology and the National Survey Research Center at Renmin University of China. The dataset used in this study was fully anonymized and did not contain any personally identifiable information.

3 Results

3.1 Sample characteristics

Table 1 presents the characteristics of the study participants. The analytic sample consisted of 6,894 empty-nest older adults. Overall, 39.34% of participants reported good sleep health, 49.25% reported average sleep health, and 11.42% reported poor sleep health. With respect to Internet use, 58.36% of participants reported never using the Internet, 8.98% reported frequent use, and 32.67% reported daily use. The sample was predominantly composed of younger older adults, with a mean age of 69.89 years. Participants aged 60–69 years comprised 50.77% of the sample, those aged 70–79 years accounted for 45.95%, and only 3.28% were aged 80 years or older. More than half of the participants resided in urban areas (56.30%). The mean years of education was 6.70 (SD = 3.92), and 28.13% of participants were currently engaged in paid work. In terms of family and psychosocial characteristics, most participants reported having children, including sons (80.79%) and daughters (69.67%). A large majority of respondents reported being satisfied with their life (70.84%). Regarding health status, 56.34% rated their health as good, and 77.56% reported having at least one chronic disease. The mean number of ADL limitations was low (Mean = 0.13, SD = 0.57), indicating that most participants were functionally independent.

Table 1 Characteristics of participants (N = 6894)

Variable	Categories	n (%) / Mean±SD
Sleep health	Good	2,712 (39.34)
	Average	3,395 (49.25)
	Poor	787 (11.42)
Frequency of Internet use	Never	4,023 (58.36)
	Often	619 (8.98)
	Daily	2,252 (32.67)
Age groups	60 – 69 years	3,500 (50.77)
	70 – 79 years	3,168 (45.95)
	80+ years	226 (3.28)
Residence	Urban	3,881 (56.30)
	Rural	3,013 (43.70)
Years of education (years)	/	6.697±3.919
Work status	At work	1,939 (28.13)
	No work	4,955 (71.87)
Has a son	Yes	5,570 (80.79)
	No	1,324 (19.21)
Has a daughter	Yes	4,803 (69.67)
	No	2,091 (30.33)
Life satisfaction	Dissatisfied	352 (5.11)
	Average	1,658 (24.05)
	Satisfied	4,884 (70.84)
Exercise duration	Less than 30 minutes	4,755 (68.97)
	30 – 59 minutes	1,463 (21.22)
	60 – 120 minutes	641 (9.30)
	More than 120 minutes	35 (0.51)
Self-rated health	Unhealthy	645 (9.36)
	Average	2,365 (34.31)
	Healthy	3,884 (56.34)

Chronic disease	Yes	5,347 (77.56)
	No	1,547 (22.44)
Number of ADL limitations	/	0.128±0.567

Note: Data are presented as number (percentage) or mean ± standard deviation (SD); ADL, activity of daily living.

3.2 Association of Internet use with sleep health

Table 2 presents the associations between frequency of Internet use and sleep health among empty-nest older adults based on two-way fixed effects models. After controlling for individual and time fixed effects as well as a comprehensive set of potential confounders, daily Internet use was significantly associated with better sleep health compared with never using the Internet (β= 0.146, 95% CI: 0.046 – 0.246, p = 0.004). In contrast, frequent but non-daily Internet use was not significantly associated with sleep health (β= 0.035, 95% CI: -0.108 – 0.177, p = 0.633). Among the covariates, older age was modestly associated with better sleep health, with participants aged 80 years and above reporting better sleep health than those aged 60–69 years (β= 0.155, 95% CI: 0.026 – 0.284, p = 0.019). Higher educational attainment was positively associated with sleep health (β= 0.306, 95% CI: 0.233 – 0.380, p < 0.001), whereas the presence of chronic disease was negatively associated with sleep health (β= -0.184, 95% CI: -0.280 – -0.088, p < 0.001).

Table 2 Associations between frequency of Internet use and sleep health

	Coef.	S.E	P-value	95% CI	
				Lower	Upper
Frequency of Internet use (ref = Never)					
Often	0.035	0.073	0.633	-0.108	0.177
Daily	0.146	0.051	0.004	0.046	0.246
Age groups (ref = Aged 60 – 69)					
Aged 70 – 79	0.035	0.021	0.093	-0.006	0.076
Aged 80+	0.155	0.066	0.019	0.026	0.284
Residence (ref = Rural)					
Urban	0.011	0.030	0.720	-0.048	0.070
Years of education	0.306	0.037	<0.001	0.233	0.380
Work status (ref = No work)					
At work	0.075	0.048	0.121	-0.020	0.169
Having a son (ref = No)					
Yes	0.666	0.328	0.042	0.023	1.309
Having a daughter (ref = No)					
Yes	0.637	0.173	<0.001	0.299	0.976
Life satisfaction (ref = Average)					
Dissatisfied	-0.033	0.120	0.780	-0.268	0.201
Satisfied	0.121	0.116	0.001	-0.107	0.349
Exercise duration (ref = Less than 30 minutes)					
30 – 59 minutes	-0.048	0.050	0.331	-0.146	0.049
60 – 120 minutes	-0.099	0.085	0.246	-0.266	0.068
More than 120 minutes	-0.292	0.226	0.196	-0.735	0.151
Self-rated health (ref = Average)					
Unhealthy	-0.104	0.096	0.279	-0.293	0.085
Healthy	0.026	0.097	0.005	-0.164	0.216
Chronic disease (ref = No)					
Yes	-0.184	0.049	<0.001	-0.280	-0.088

Number of ADL limitations	-0.017	0.053	0.744	-0.121	0.087
Constant	-0.738	0.427	0.084	-1.574	0.099

Note: Two-way fixed-effects models were applied to examine the association between frequency of Internet use and sleep health, controlling for both individual and time fixed effects; All models adjusted for age, residence, years of education, work status, having a son, having a daughter, life satisfaction, exercise duration, self-rated health, presence of chronic disease, and number of ADL limitations; Robust standard errors were clustered at the individual level; CI = confidence interval; ADL, activities of daily living.

3.3 Sensitivity analyses

Table 3 presents a series of sensitivity analyses conducted to assess the robustness of the main findings. Across all specifications, the results were broadly consistent with the baseline estimates, lending support to the robustness of the observed association between Internet use and sleep health among empty-nest older adults. In Model 1, Internet use was operationalized as a binary variable. Older adults who used the Internet reported significantly better sleep health than non-users (β= 0.119, 95% CI: 0.026 – 0.213, p = 0.012). In Model 2, where the outcome variable was redefined as a binary indicator of healthy sleep, daily Internet use remained positively associated with healthy sleep (β= 0.085, 95% CI: 0.015 – 0.156, p = 0.018), whereas frequent but non-daily use showed no significant association. Model 3 estimated cross-sectional associations using the 2023 survey wave only. Consistent with the main analysis, daily Internet use was significantly associated with better sleep health (β= 0.103, 95% CI: 0.009 – 0.196, p = 0.031), while frequent use was not. In Model 4, after excluding respondents with severe functional limitations, the positive association between daily Internet use and sleep health persisted (β= 0.152, 95% CI: 0.052 – 0.253, p = 0.003).

Taken together, these sensitivity analyses suggest that the observed association between daily Internet use and better sleep health is robust to alternative model specifications, variable definitions, and sample restrictions.

Table 3 Sensitivity analysis on associations between frequency of Internet use and sleep health

	Coef.	S.E	P-value	95% CI	
				Lower	Upper
Model 1 (N = 6894)					
Internet use (ref = No)					
Yes	0.119	0.048	0.012	0.026	0.213
Covariates	Yes				
Model 2 (N = 6894)					
Frequency of Internet use (ref = Never)					
Often	-0.003	0.051	0.955	-0.103	0.098
Daily	0.085	0.036	0.018	0.015	0.156
Covariates	Yes				
Model 3 (N = 10850)					
Frequency of Internet use (ref = Never)					
Often	0.013	0.068	0.850	-0.121	0.147
Daily	0.103	0.048	0.031	0.009	0.196
Covariates	Yes				
Model 4 (N = 6850)					
Frequency of Internet use (ref = Never)					
Often	0.032	0.072	0.657	-0.109	0.172
Daily	0.152	0.051	0.003	0.052	0.253
Covariates	Yes				

Note: In Model 1, the key explanatory variable was replaced with a binary indicator of Internet use; in Model 2, the outcome variable was redefined as a binary indicator of healthy sleep; Modelm3 estimated cross-sectional associations using data from the 2023 survey wave only; Model 4 excluded respondents with severe functional limitations. All models controlled for the same set of covariates as in the baseline analysis. Robust standard errors were reported. CI, confidence interval; S.E., standard error.

3.4 Stratified analyses by age group and place of residence

Table 4 presents stratified analyses examining whether the association between frequency of Internet use and sleep health was observed across age groups and residential settings among empty-nest older

adults. Among older adults aged 60 – 79 years, daily Internet use was positively associated with sleep health (β= 0.135, 95% CI: 0.033 – 0.237, p = 0.009), whereas frequent but non-daily use showed no statistically significant association. In contrast, among those aged 80 years and above, frequent Internet use was strongly associated with better sleep health (β= 1.476, 95% CI: 0.723 – 2.229, p < 0.001), while daily use was not significantly related to sleep health. Estimates for the oldest-old should be interpreted with caution given the relatively small sample size in this subgroup. Stratification by residence revealed broadly similar patterns in urban and rural settings. Daily Internet use was significantly associated with better sleep health among both urban (β= 0.144, 95% CI: 0.016 – 0.272, p = 0.028) and rural older adults (β= 0.190, 95% CI: 0.015 – 0.366, p = 0.034). In contrast, frequent Internet use did not show statistically significant associations with sleep health in either group. Overall, the stratified analyses suggest that the association between Internet use and sleep health may manifest differently across population subgroups.

Table 4 Heterogeneity analysis by age and residence

	60-79 years (N = 6668)		**80+ years (N = 226)**	
	Coef. (95% CI)	P-value	Coef. (95% CI)	P-value
Frequency of Internet use (ref = Never)				
Often	0.015 (-0.128 – 0.158)	0.833	1.476 (0.723 – 2.229)	<0.001
Daily	0.135 (0.033 – 0.237)	0.009	0.114 (-0.748 – 0.977)	0.794
Covariates	Yes		Yes	
	Urban (N = 3881)		**Rural (N = 3013)**	
	Coef. (95% CI)	P-value	Coef. (95% CI)	P-value
Frequency of Internet use (ref = Never)				
Often	0.042 (-0.134 – 0.218)	0.641	0.079 (-0.167 – 0.324)	0.531
Daily	0.144 (0.016 – 0.272)	0.028	0.190 (0.015 – 0.366)	0.034
Covariates	Yes		Yes	

Note: Two-way fixed-effects models were applied to examine the association between frequency of Internet use and sleep health, controlling for both individual and time fixed effects; All models adjusted for age, residence, years of education, work status, having a son, having a daughter, life satisfaction,

exercise duration, self-rated health, presence of chronic disease, and number of ADL limitations; Robust standard errors were clustered at the individual level; CI = confidence interval.

3.5 Extended analyses by functional types of Internet use

Here, Internet use was further classified into three functional types based on reported online activities: social interaction (voice/video chat and text messaging), information entertainment (browsing news or articles, listening to music, watching videos, and listening to the radio), and tool function (transportation and health management). Observations with missing values on any of the corresponding Internet use content variables were excluded from the relevant analyses.

Table 5 presents extended analyses examining the associations between different functional types of Internet use and sleep health among empty-nest older adults. When each functional type was examined separately, the information entertainment type was positively associated with sleep health (β= 0.228, 95% CI: 0.014 – 0.443, p = 0.037). In contrast, no statistically significant associations were observed for the social interaction type (β= -0.138, 95% CI: -0.701 – 0.425, p = 0.630) or the tool function type (β= 0.085, 95% CI: -0.069 – 0.239, p = 0.279). When all three functional types were included simultaneously in the same model, the positive association between information entertainment type and sleep health remained statistically significant (β= 0.247, 95% CI: 0.028 – 0.466, p = 0.027). The associations for social interaction and tool function types remained non-significant. These findings suggest that the observed association between Internet use and sleep health may be primarily driven by information-related and entertainment-related online activities, rather than by social interaction or utilitarian uses.

Table 5 Extended analyses of the associations between functional types of Internet use and sleep health

	Coef.	S.E	P-value	95% CI	
				Lower	Upper
Model 1 (N = 2,871)					
Social interaction type (ref = No)					
Yes	-0.138	0.287	0.630	-0.701	0.425
Covariates	Yes				
Model 2 (N = 2871)					
Information entertainment type (ref = No)					
Yes	0.228	0.109	0.037	0.014	0.443
Covariates	Yes				
Model 3 (N = 2871)					
Tool function type (ref = No)					
Yes	0.085	0.078	0.279	-0.069	0.239
Covariates	Yes				
Model 4 (N = 2871)					
Social interaction type (ref = No)					
Yes	-0.156	0.285	0.584	-0.714	0.403
Information entertainment type (ref = No)					
Yes	0.247	0.112	0.027	0.028	0.466
Tool function type (ref = No)					
Yes	0.109	0.079	0.170	-0.047	0.264
Covariates	Yes				

Note: M1–M3 estimated the associations between each functional type of Internet use and sleep health separately; M4 included all three functional types simultaneously in the same model. All models controlled for the same set of covariates as in the baseline analysis. Robust standard errors were reported. S.E., standard error; CI, confidence interval.

4 Discussion

Using nationally representative longitudinal data from the China Longitudinal Aging Social Survey collected in 2020 and 2023, this study examined the association between Internet use and sleep health among empty-nest older adults in China. Several important findings emerged. First, Internet use was

positively associated with better sleep health, with daily Internet engagement showing the strongest effect compared with non-use.. Second, this association exhibited clear age-related heterogeneity: daily Internet use was more beneficial for younger-old empty-nest adults, whereas frequent but non-daily use was more strongly associated with improved sleep health among the oldest-old. Third, no significant urban–rural differences were observed in the association between Internet use and sleep health. The positive association between Internet use and sleep health of empty-nest oleder adults is significant in both urban and rural areas. Finally, when distinguishing functional types of Internet use, only information and entertainment-oriented use was significantly associated with better sleep health, while social interaction type and tool founction type showed no significant effects.

4.1 Internet use and sleep health among empty-nest older adults

Sleep health is a central component of healthy ageing and is shaped by complex interactions between physiological, psychological, and social factors[29-31]. Empty-nest older adults are particularly vulnerable to sleep problems due to reduced daily family support and increased risks of loneliness and emotional distress[32]. Against this background, the positive association between Internet use and sleep health suggests that digital engagement may serve as a compensatory resource for this subgroup[15,33].

Several mechanisms may explain this relationship. First, Internet use facilitates access to health-related information and online services, which may improve health literacy and promote healthier daily routines. Second, entertainment-oriented online activities can provide emotional relaxation and stress relief, thereby reducing anxiety and negative affect before sleep. Third, digital communication may help maintain social ties with family members and peers, alleviating loneliness and psychological vulnerability, both of which are closely linked to sleep quality.

These findings are consistent with previous studies showing beneficial effects of moderate Internet use on older adults' mental health and sleep outcomes. Importantly, by focusing specifically on empty-nest older adults, this study demonstrates that the health implications of Internet use are shaped by family structure and living arrangements. This extends prior research that has largely treated older adults as a homogeneous population and underscores the need to incorporate household context into analyses of digital engagement and health in later life.

4.2 Age-related heterogeneity in the association between Internet use and sleep health

This study identified clear age-related differences in the relationship between Internet use and sleep health. Among younger-old empty-nest adults, daily Internet use was associated with better sleep health,

whereas among the oldest-old, frequent but non-daily use showed the strongest positive association. These differences likely reflect variations in digital literacy, physical functioning, and patterns of technology engagement across age groups. Younger-old adults generally possess higher digital competence and greater cognitive flexibility, enabling them to integrate Internet use into daily life without excessive mental or physical burden. Regular engagement may help regulate emotions, enrich leisure activities, and help maintain structured daily routines conducive to healthy sleep. In contrast, the oldest-old often experience declining physical capacity and increased fatigue, making intensive daily Internet use potentially overstimulating. For this group, moderate and purposeful Internet engagement may better balance the benefits of information access and emotional support with the need to avoid excessive cognitive arousal. This interpretation aligns with prior evidence suggesting that the health effects of digital technology use are moderated by age, functional status, and living context[34-36]. These findings underscore the importance of tailoring digital health interventions according to age-specific needs and capacities among empty-nest older adults.

4.3 Urban-rural similarities in the effects of Internet use

Contrary to some previous studies reporting urban-rural disparities in the health effects of Internet use[37], this study found no significant differences between urban and rural empty-nest older adults. One plausible explanation is the rapid expansion of digital infrastructure and smartphone penetration in rural China over the past decade, which has substantially narrowed the digital access gap[38]. With improved connectivity, rural empty-nest older adults may now access online information, entertainment, and communication in ways increasingly similar to their urban counterparts. Cross-national evidence further suggests that in contexts with widespread Internet penetration, the association between Internet use and health outcomes among older adults tends to be relatively uniform across regions[39]. This finding suggests that digital inclusion policies may contribute to reducing regional inequalities in sleep health and supports the feasibility of implementing unified digital ageing strategies across both urban and rural settings.

4.4 Functional types of Internet use and sleep health

A central contribution of this study lies in distinguishing functional types of Internet use. Only information and entertainment-oriented use was positively associated with sleep health, whereas social interaction and tool founction types showed no significant associations.

This pattern can be interpreted through the framework of Uses and Gratifications Theory, which emphasizes that individuals actively select media to satisfy specific psychological needs[40]. Information and entertainment-oriented activities may directly fulfill needs for emotional comfort, cognitive engagement, and relaxation, thereby reducing stress and facilitating sleep. In contrast, social interaction-oriented Internet use does not necessarily guarantee positive emotional experiences. Communication with adult children or relatives may involve family concerns or intergenerational

tensions, potentially increasing emotional arousal rather than promoting relaxation before sleep. Similarly, tool founction type often requires higher levels of digital skill and problem-solving. For empty-nest older adults lacking immediate family assistance, difficulties encountered during such activities may generate frustration and anxiety, offsetting potential benefits for sleep health[25]. These findings highlight that the health implications of Internet use depend not only on frequency but also on the purposes for which digital technologies are used, emphasizing the importance of differentiating functional patterns of digital engagement in gerontological research.

4.5 Strengths and limitations

This study has several notable strengths. First, it focuses on empty-nest older adults, a rapidly expanding and vulnerable subgroup of the ageing population, thereby highlighting the contextual role of living arrangements in shaping the health effects of Internet use. Second, it advances measurement by distinguishing both frequency and functional types of Internet use, moving beyond a simple user–non-user dichotomy. Third, by employing longitudinal panel data and two-way fixed effects models, this study captures within-person changes over time, thereby reducing bias from unobserved time-invariant individual characteristics, providing more robust evidence on the association between Internet use and sleep health.

Several limitations should also be acknowledged. First, sleep health was assessed using relatively simple self-reported measures due to data availability, and future studies should incorporate more comprehensive and objective sleep indicators. Second, this study did not directly examine the psychological and behavioral mechanisms linking different types of Internet use to sleep health. Third, the sample was restricted to empty-nest older adults in China, and the generalizability of the findings to other cultural and institutional contexts requires further investigation. Future research should explore causal mechanisms, examine long-term trajectories of digital engagement and sleep health, and consider cross-national comparisons to better understand how social and technological environments shape ageing outcomes.

5 Conclusion

This study provides longitudinal evidence that Internet use is positively associated with sleep health among empty-nest older adults in China. Regular Internet engagement, especially information and entertainment-oriented use, was linked to better sleep outcomes. The association remained robust across multiple model specifications and sample restrictions. Age-related heterogeneity was observed, suggesting that the benefits of Internet use for sleep health differ across later-life stages, whereas no significant urban–rural disparities were identified. By focusing on empty-nest older adults as a distinct population and distinguishing functional types of Internet use, this study extends existing research that has largely treated older adults as a homogeneous group and relied on cross-sectional data. The

findings underscore the importance of considering both living arrangements and usage patterns when assessing the health implications of digital engagement in later life.

From a policy perspective, the results suggest that promoting appropriate and purposeful Internet use may contribute to improving sleep health and overall well-being among empty-nest older adults. Digital inclusion strategies should prioritize age-appropriate guidance and support, with particular attention to fostering information and entertainment-based online activities while avoiding excessive or poorly timed use. In the context of rapid population ageing, integrating digital health interventions into community-based ageing services may offer a feasible pathway toward healthier and more equitable ageing in China and other ageing societies.

Declarations

Ethics approval and consent to participate

This study used secondary data from the China Longitudinal Aging Social Survey (CLASS). All procedures involving human participants were conducted in accordance with the Declaration of Helsinki and its later amendments. The survey protocol was approved by the Academic Committee of School of Population and Health, Renmin University of China. Verbal informed consent was obtained from all participants prior to the interviews. Information on the consent process, including agreement to participate and reasons for refusal, was documented and archived by the Institute of Gerontology and the National Survey Research Center at Renmin University of China. The dataset used in this study was fully anonymized and did not contain any personally identifiable information.

Consent for publication

Not applicable.

Availability of data and materials

The dataset supporting the conclusions of this article is available in the the China Longitudinal Aging Social Survey (CLASS) repository, unique persistent identifier and hyperlink to dataset(s) in http://class.ruc.edu.cn/.

Competing interests

The authors declare that they have no competing interests.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

WQZ and ZM conceived this research, gathered resources, curated all data, and wrote/prepared the original draft. ZS conducted software analyses and responsible for visualization. ZM conducted necessary validations and was responsible for project administration. All authors contributed to the article and approved the submitted version. All authors reviewed the manuscript.

Acknowledgements

The authors gratefully acknowledge the Institute of Gerontology and the National Survey Research Center at Renmin University of China for providing access to the China Longitudinal Aging Social Survey (CLASS) data. We also thank all participants who took part in the survey.

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Figures

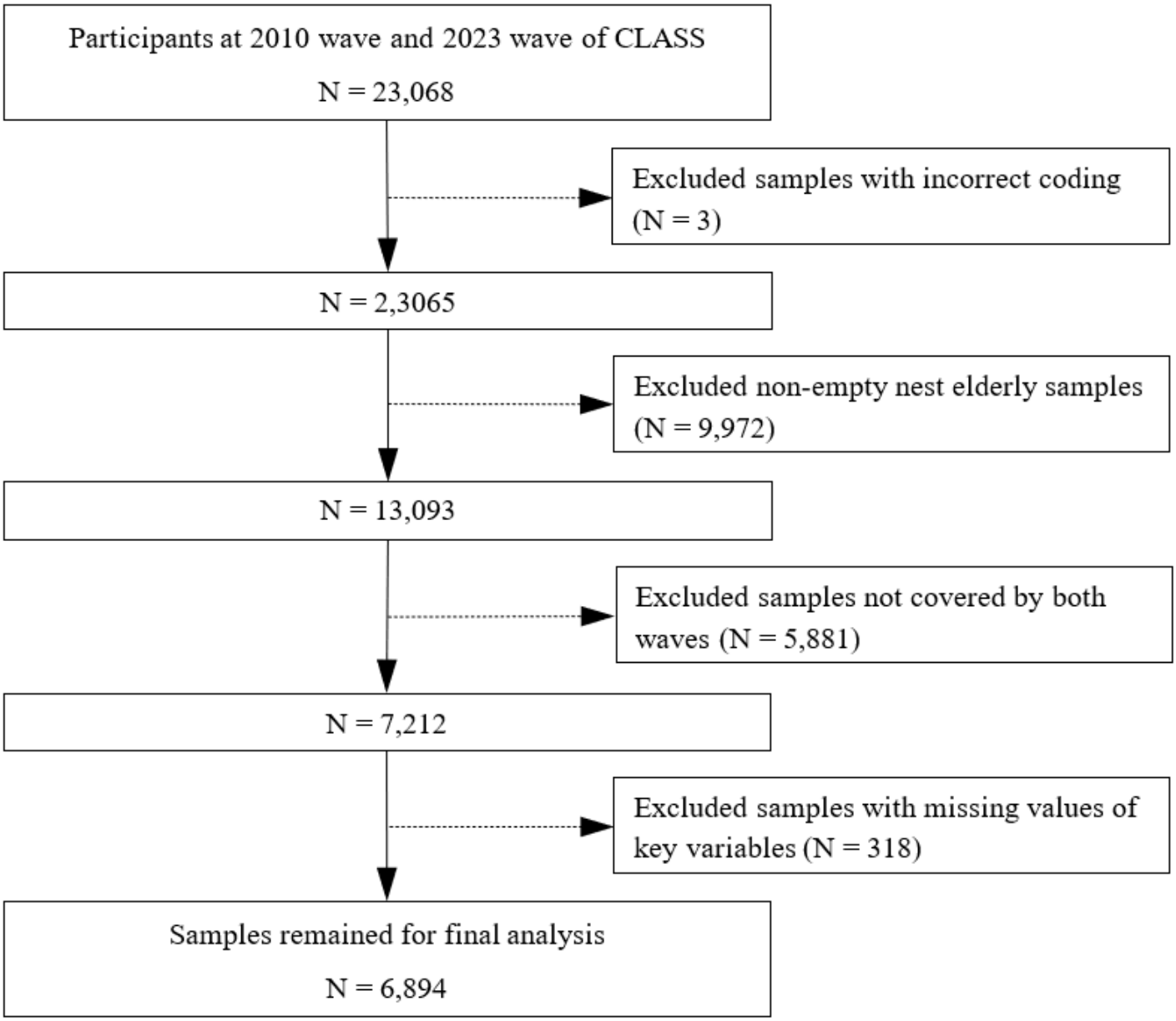


Figure 1

Flow chart of the study population selection process